PHYSICS AT 100-200 TeV

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I. Brief Introduction:

- Particle Physics and Colliders

II. Physics Expectations at the VLHC:

- Representative SM Physics
- Physics Beyond the SM

III. Physics at the High-Energy Frontier

- Beyond the Naive Expectation

- $M_W,\ M_Z$? (Gauge symmetry breaking)
- $m_t,\ m_f,\ m_\nu$? (fermion masses and mixing)
- $M_H \sim \mathcal{O}(M_Z)$? (natural EW scale)
- Supersymmetry? ($M_Z - M_{pl}$ hierarchy)
- Techni-/top-color? (dynamical symm. brkng)
- Superstring? (quantum gravity)
- large extra dimensions? (gravity+hierarchy)
- ... ...? (... ...)

A. HERA

1998: $\sqrt{s} = 314$ GeV with 40 pb^{-1}/detector;

2006: $\sqrt{s} = 314$ GeV with 1 fb^{-1}/detector.

B. LEP2

1998: $\sqrt{s} = 189$ GeV with 200 pb^{-1}/detector;

2000: $\sqrt{s} \sim 203$ GeV with 500 pb^{-1}/detector (1998+1999+2000).

C. Tevatron and Upgrade

Current: $\sqrt{s} = 1.8$ TeV with ~ 100 pb^{-1}/detector;

TeV2000: $\sqrt{s} = 2$ TeV with ≥ 2 fb^{-1}/detector

TeV33 2006: $\sqrt{s} = 2$ TeV with 30 fb^{-1}/detector

D. LHC

2005: $\sqrt{s} = 14$ TeV with 10 fb^{-1}/detector/yr

200x: $\sqrt{s} = 14$ TeV with 100 fb^{-1}/detector/yr

E. e^+e^- Linear Colliders

NLC 200x: $\sqrt{s} \sim 0.3-0.5$ TeV with 50 fb^{-1}/yr

N^{n}LC: $\sqrt{s} \sim 1.5$ TeV with 200 fb^{-1}/yr

F. Very Large Hadron Collider

VLHC: $\sqrt{s} \sim 100 - 200$ TeV with 100 fb^{-1}/yr

G. $\mu^+\mu^-$ Colliders

FMC: $\sqrt{s} \sim m_h$ with 0.1-1 fb^{-1}/yr

NMC: $\sqrt{s} \sim 3 - 4$ TeV with 100-1000 fb^{-1}/yr

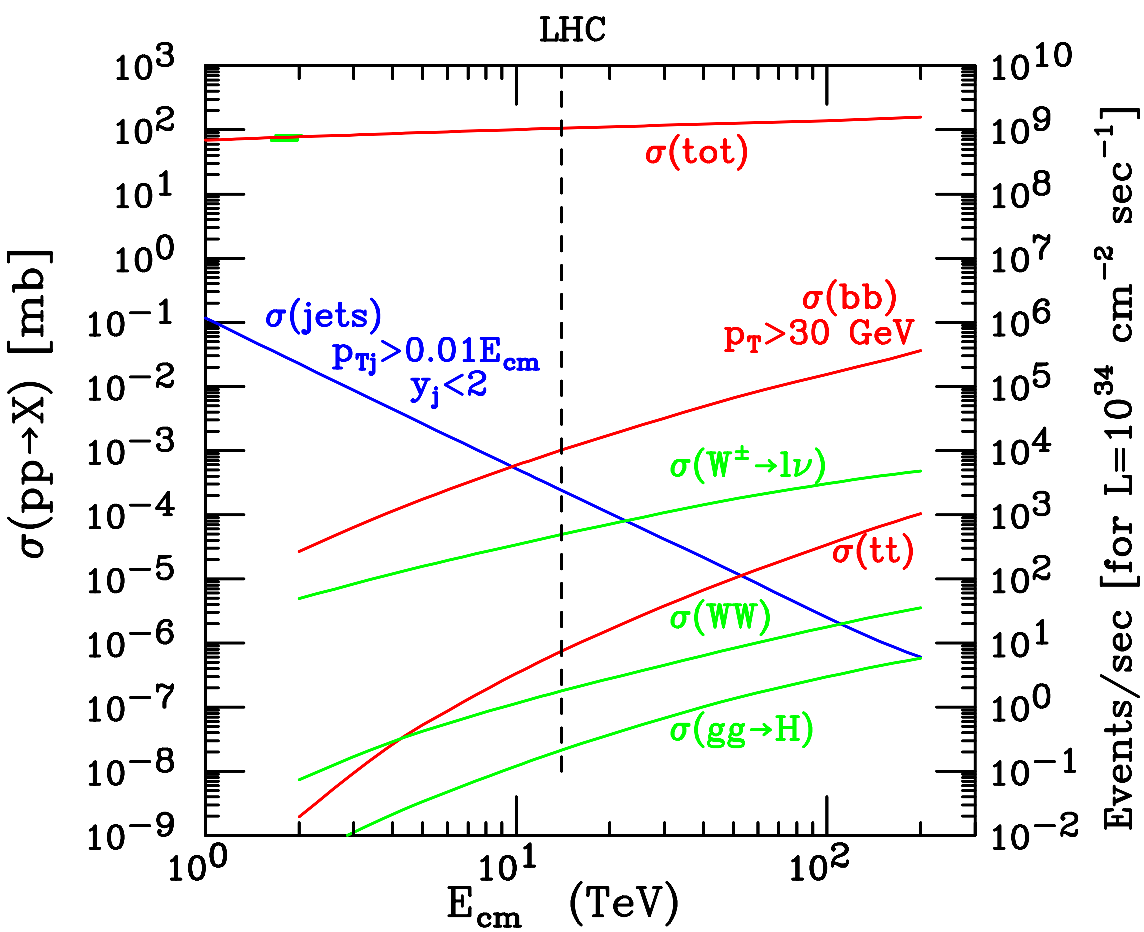
II. Physics Expectations at The VLHC

- Representative SM Physics:

  1. QCD physics; $\sigma(tot)$ at highest energies

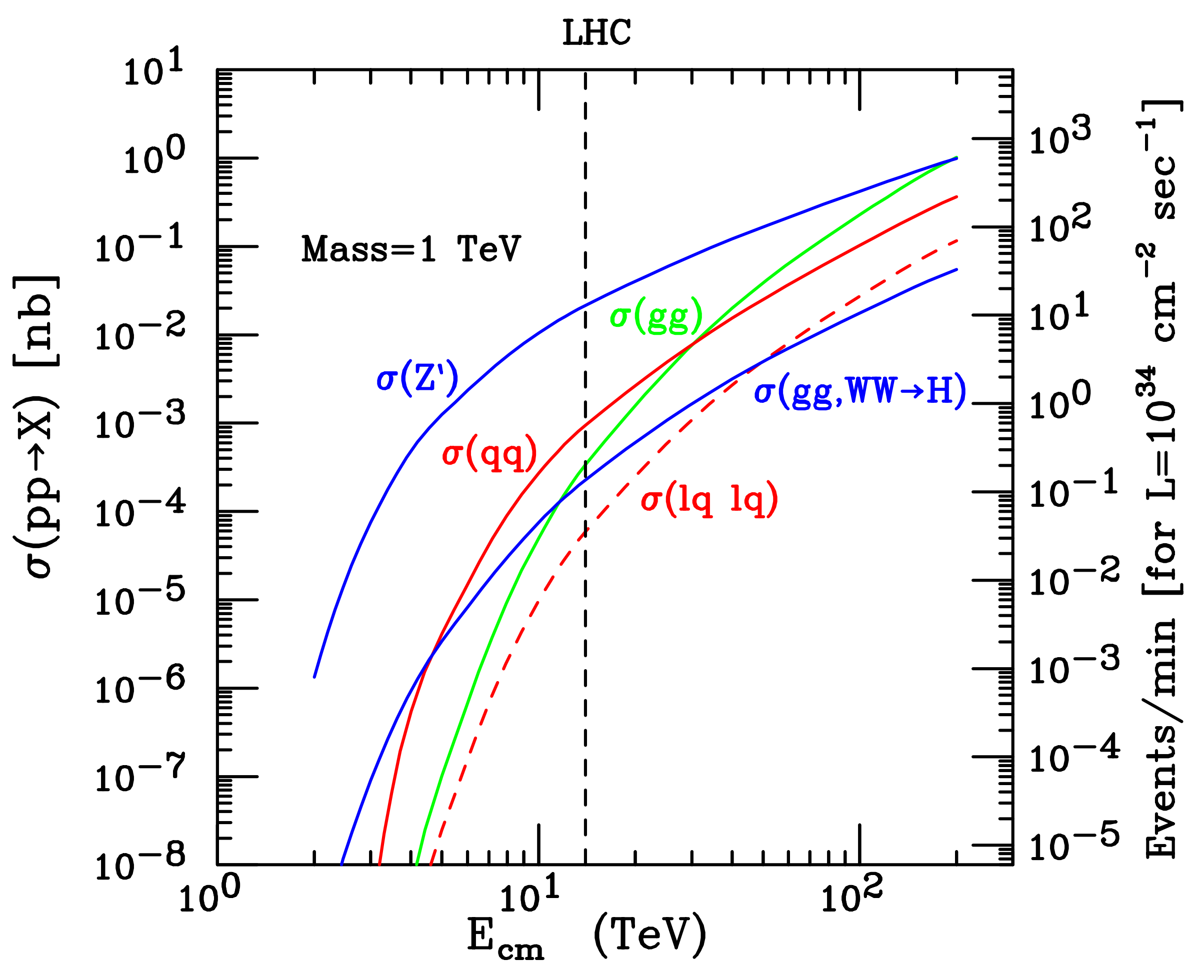
  2. truly factories for: $b\bar{b}$, $t\bar{t}$, $Z/W^{\pm}$, W^+W^-...

  3. SM Higgs factory



- New Physics Beyond the SM

1. SUSY states: $\tilde{q}\bar{\tilde{q}}$, $\tilde{g}\tilde{g}$
2. new heavy particles: Z', $W_R^{\pm}$, lq
3. very heavy Higgs



III. High-Energy Frontier: Beyond the LHC

(a) Multi-TeV Squarks: $\tilde{u}$, $\tilde{d}$

$\tilde{t}$ is at $\mathcal{O}$(1 TeV) (EW hierarchy)

$\tilde{q}$ are at $\mathcal{O}$(5 TeV) (FCNC)

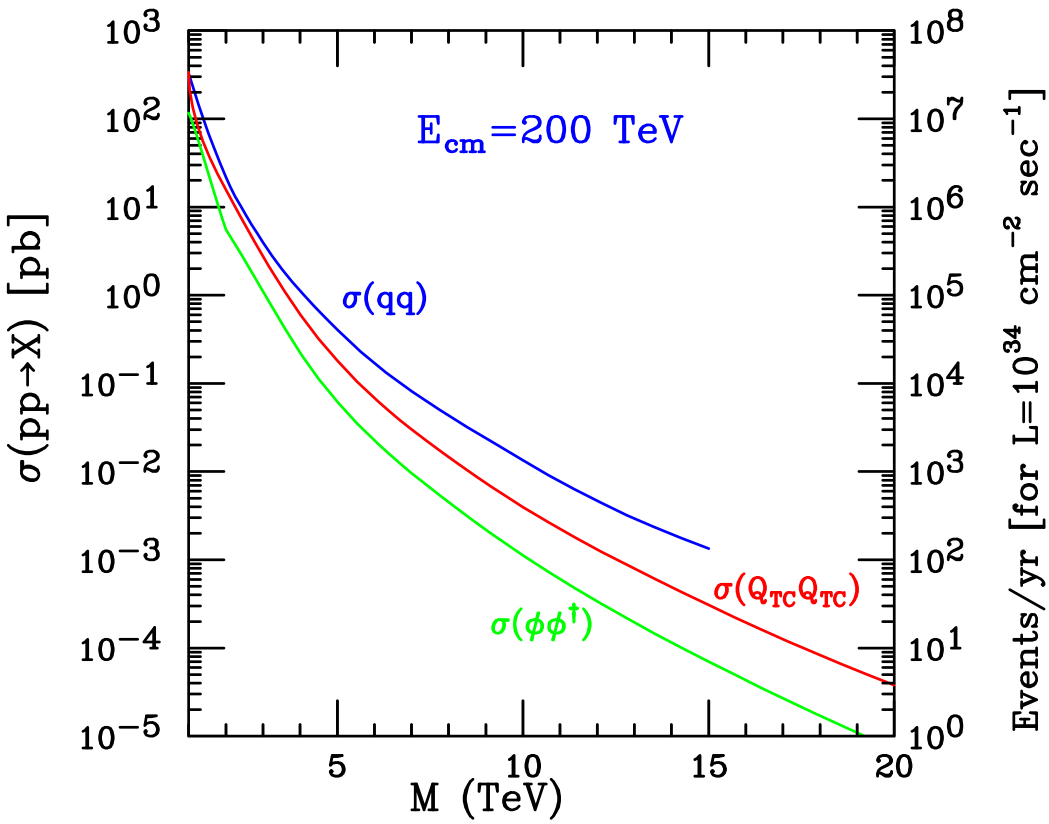
(b) SUSY Breaking Messengers:

Φ, $\bar{\Phi}$ are at $\mathcal{O}(10-100$ TeV)

(c) Technicolor Jets:

Final Technicolor Manifestation:

very massive jets $U_{TC} \to \pi^+_{TC}\pi^0_{TC}X \to t\bar{b}, b\bar{b}, X$



(d) Strongly-interacting Electroweak Sector:

If no $h_i/SUSY$ found before and at the LHC,

$W_L W_L$ Scattering must reveal new dynamics

- $\Lambda_{EW}(W_L W_L \to W_L W_L) \sim \sqrt{8\pi}\ v \sim$1.2 TeV.

$\sqrt{s_W} \sim 2$ TeV $\Rightarrow \sqrt{s_f} > 4$ TeV $\Rightarrow \sqrt{s_p} > 65$ TeV

$$\frac{\sigma(W_L^+ W_L^- \to W_L^+ W_L^-)}{\sigma(W_L^+ W_L^- \to Z_L Z_L)} \begin{cases} \sim 2 & \text{scalar } H^0, \\ \gg 1 & \text{vector } \rho^0_{TC}, \\ \sim 2/3 & \text{LET } \sqrt{s} \ll M. \end{cases}$$

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$$\Lambda(W_L^+ W_L^- \to f\bar{f}) = \frac{8\pi v^2}{3 m_f} \sim \begin{cases} 3 \text{ TeV} & m_t = 175 \text{ GeV} \\ 97 \text{ TeV} & m_b = 5 \text{ GeV}. \end{cases}$$

(e) Contact Interactions: Compositeness?

New heavy bosons and quark/lepton sub-structure lead to 4-fermion contact interactions:

$$4\pi \frac{\kappa}{\Lambda^2}\ \bar{\psi}_{f1},\ {}_{\mu}\psi_{f1}\ \bar{\psi}_{f2},\ {}^{\mu}\psi_{f2}$$

The best channel at hadron colliders is the DY process:

$$pp \to \gamma^*, Z \to e^+e^-/\mu^+\mu^- + X$$

The Sensitivity to the "composite scale Λ" goes like

$$\frac{s^2}{\Lambda^4},$$

so that:

$$\frac{(1.8\ \text{TeV})^4}{(3\ \text{TeV})^4} \sim \frac{(14\ \text{TeV})^4}{(25\ \text{TeV})^4} \sim \frac{(100\ \text{TeV})^4}{(170\ \text{TeV})^4}$$

$$170\ \text{TeV} \Rightarrow 10^{-18}\ \text{cm !}$$

(f) Multi-W, H production via Sphalerons

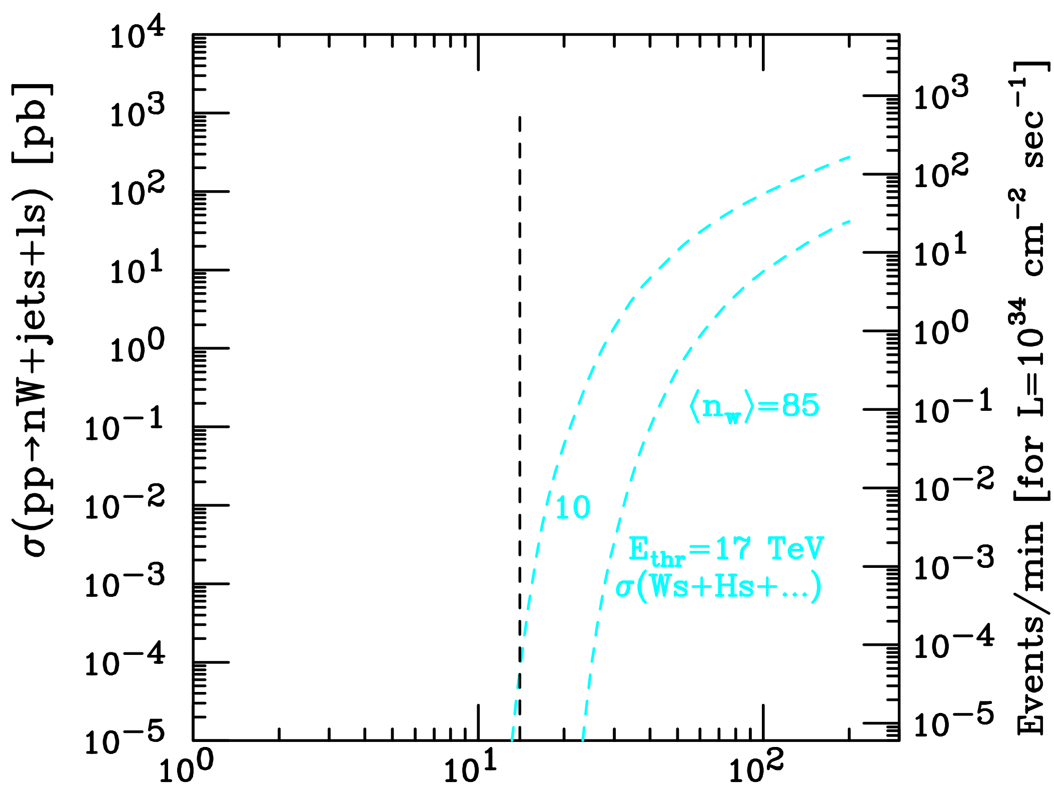
Electroweak instantons (sphalerons) induce $B + L$ violating transition

$$qq \to 7\bar{q} + 3\bar{\ell} + n_w W^{\pm} + n_h H$$

with total cross section

$$\sigma(tot) \sim e^{-2\pi/\alpha_w}\ e^{\alpha_w s/M_W^2} \leq \frac{16\pi}{s}.$$

$\Rightarrow$ Enhanced for $\sqrt{s} > M_W/\alpha_w$, bound by unitarity.



(g) String State Excitation

If the superstring (or quantum gravity) scale is as low as $\mathcal{O}(1-10\ \text{TeV})$, then the new physics threshold opens at the VLHC:

Many Kaluza-Klein/Regge states produced, as well as BLACK HOLES

For more details, call Prof. Dimopoulos ...

Other Issues Not Mentioned:

- Physics with Booster-Tunnel Collider?
(6-25 TeV)

- Detector demands:

  1. very high event rate
  2. vertexing?
  3. coverage: forward region?
  4. tracking? very energetic (multi-TeV) particles

- Earlier Refs.:

  1. The European Long Interacting Storage Accelerator (ELOISTRON)
  2. Snowmass Report: (D. Denisov and S. Keller)
  3. VLHC Working Group Report: (D. Denisov and S. Keller et al.)

CONCLUSIONS

- VLHC has a rich experimental program beyond next generation of colliders: LHC/TeV Lepton colliders, on MANY physics topics you can think of

- High energy/high luminosity frontier may uncover unexpected that can revolutionize our understanding of particle physics.